EARTHQUAKES: THEIR CAUSES AND EFFECTS.

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The occurrence of three earthquakes in the western hemisphere within the space of nine months in 1906–1907, all of which were attended with disastrous effects upon human life and property, attracted as never before the attention of the world, and particularly of the United States, and focused interest upon the science of seismology in a manner calculated to advance materially the study of movements and other physical changes in the earth's crust. San Francisco, in April, 1906, Valparaiso, in August, 1906, and Kingston, in January 1907, attracted wide notice, but the disaster that overwhelmed Messina, Reggio and vicinity on December 28, 1908, capped the climax, and sufficient reason is apparent for the universal interest now prevailing, one manifestation of which is the present symposium. The thesis of the seismologists is that the chain of earthquake observatories that have been established in the past decade and a half should be extended and united into a network of stations covering the globe, sufficiently, at least, to furnish a complete record of the important vibrations propagated through the earth, indicate their places of origin and provide data for more satisfactory theories as to their causes.

Great earthquakes rank with volcanic eruptions as being the most terrifying of all natural phenomena. Usually coming with no recognized warning, often happening in the night, extremely indefinite as to source, extent and duration, they fill the mind of the human observer with the horror of utter helplessness. They have been far more destructive to human life and property than volcanic eruptions have been, for we have the earthquake shocks of Sicily, 1693, with 60,000 victims; Yeddo, Japan, 1703 (200,000); Peking, 1731 (100,000); Lisbon, 1755 (60,000); Calabria, 1783 (60,000) and Messina-Reggio, 1908 (200,000); besides many others, to compare with the volcanic outbursts of Krakatoa, 1883, destroying 36,500 victims; Vesuvius, 1663 (18,000); Mt. Pelé, 1902 (29,000) and the Soufrière of St. Vincent, 1902 (1,400), other historic eruptions having entailed comparatively small loss of life.

Although earthquakes have been recorded frequently throughout all historic time, seismology is one of the youngest of the sciences —it is still in its formative state. Scientific interest in the subject has indeed not been lacking, but real edvance was retarded by the fact that, up to the latter part of the nineteenth century, the causes of the phenomena were sought without rather than within the earth itself. Geology was not seriously called upon for aid in solving the problems.

The modern science of seismology is generally held to have had its beginning with the publication, in 1862, of Robert Mallet's great book upon the so-called Neapolitan, or better Basilicata, earthquake of 1857. Mallet, however, approached his task with the preconceived idea that earthquakes were always caused by subterranean explosions, and his observations and deductions were warped accordinigly. The science received its real start from Eduard Suess, when he published in 1874[1] his brilliant generalization showing the intimate association of more than forty Austrian earthquakes with the already well-known Kamp, Thermen and Mürz fault lines near Vienna and postulated crustal movements as an important cause of seismic disturbances, thus combatting the "centrum" theory of Mallet and others. Suess followed this paper with a still more important paper[2] the next year along the same lines showing the intimate relation of the great earthquakes of southern Italy and Sicily to the fault zones of the region. Impetus was added by the publication of the illuminating treatise of Rudolph Hoernes[3] in 1878, in which earthquakes were first definitely classified into (1) those due to the collapse of the roofs of cavities within the earth's crust, (2) those resulting from explosions connected with volcanic eruptions and (3) tectonic quakes, or those caused by crustal movements along fault planes or due to other effects of the action of mountain-

[1] "Die Erdbeben Nieder-Oesterreichs," *Denkschr. k. Akad. Wiss.*, Wien, XXXIII., Abth. I., p. 61, 1874.

[2] "Die Erdbeben des südlichen Italien," *id.*, XXXIV., Abth. I., p. 1, 1875.

[3] *Jahrbuch d. k. k. Geol. Reichsanstalt*, XXVIII., p. 387, Wien, 1878.

building forces. Many others in Europe, Japan and America have contributed to the advance of seismology, but particular mention should be made of the services of Professor John Milne, of England, whose long residence in Japan and intimate study of the earthquake phenomena of that and other uneasy regions have enabled him to contribute more than any other one person to the advance of the new science.

The perfecting of instruments for the purpose of recording movements of every kind in the surface of the earth has vastly extended our knowledge of the character of earth vibrations and enhanced the value of deductions affecting the theory of earthquakes. The instrumental study of earthquakes by means of seismographs, however, can hardly be said to antedate the year 1892, but within the past decade and a half the number of fully equipped earthquake stations has vastly increased, the growth having been considerably accelerated through the interest aroused by the disasters of the last three years. There are now in Great Britain and her colonies fifty seismographic stations equipped with the same type of instrument, while in all the world there are more than two hundred stations equipped with instruments capable of recording world-shaking earthquakes. More than half of these stations are in Europe.

No large part of the surface of the globe seems to be entirely stable, but certain regions or zones are much more liable than others to the occurrence of earthquakes. If we study a map of the world upon which their location has been plotted, we find in the eastern hemisphere a broad belt of seismic activity extending from west to east through the Mediterranean Sea, Persia, the southern Himalayas and the Sumatra-Java group of islands. A branch zone stretches from the southern end of the Caspian Sea northeastward half way across Asia. This is de Montessus de Ballore's "Alps-Caucasus-Himalayas" belt and it has furnished more than 53 per cent. of recorded shocks.[4] A seismic belt practically encircles the Pacific Ocean, the principal points in it being the Japanese Archipelago, Alaska, California, Southern Mexico and Central America and the

[4] F. de Montessus de Ballore, "Les tremblements de terre," p. 24, Paris, 1906.

northern and southern Andes. This "Circum-Pacific" or "Andes-Japan-Malay" belt has given 41 per cent. of the quakes. In the western hemisphere in addition to a part of the circum-Pacific belt, there are the West India Islands and the mountains of Venezuela forming a seismic zone. Earthquakes mostly of volcanic origin have visited many of the islands of the South Seas. The major portions of Africa and South America remain blank upon such a map, probably because little is known about their seismicity.

We are in the habit of thinking of eastern North America as a region free from earthquake shocks. The impression, however, is erroneous, since New England has experienced about 250 recorded shocks since the Pilgrims landed at Plymouth, and there have been at least four great earthquakes in the eastern half of the continent within the past two and one half centuries, one on the fifth of February, 1663, which affected the St. Lawrence Valley over an area more than six hundred miles long and three hundred miles wide as described in the "Jesuit Relations."[5] In 1811–1812 heavy quakes occurred in the central part of the Mississippi Valley, accompanied with considerable subsidence fifty miles south of the junction of the Ohio and Mississippi Rivers. Strong shocks continued for more than a year and evidence of the sinking still persists in lakes and submerged trees. The southeastern part of the United States was the center of an earthquake shock January 4, 1843, the waves of which were felt at points at least eight hundred miles apart.[6] In 1886 occurred the Charleston earthquake, an event still fresh in the minds of most of our population.

As to earthquakes of the several classes, the falling in of the roof of a buried cavity causes slight shocks. Quakes of this kind have often been reported from certain parts of Switzerland, the Tyrol and elsewhere, but all have been local in character. It seems certain too that the blocks falling in the caverns of southern Indiana and Kentucky produced vibrations sensible on the surface, but reports of such have not come under my eye.

Earthquakes arising from volcanic explosions or associated with eruptions form a much more important subdivision. Until within

[5] W. H. Hobbs, "Earthquakes," p. 315, New York, 1908.
[6] H. D. Rogers, *Am. Jour. Sci.*, I., XLV., 342, 1843.

thirty-five years, indeed, it was the general belief that volcanic earthquakes were by far the most numerous and destructive of all. This idea controlled and vitiated Mallet's work, but it is now known to be erroneous, for although it is true that earthquake zones coincide in part with belts of volcanic activity, shocks are more frequent and more severe in non-volcanic regions. The severest quakes of South America have not happened around the great volcanoes; the shocks of California are evidently independent of the now extinct or at any rate dormant volcanoes of the Cascade Range; the recent (1899) great earthquakes of Alaska were in the vicinity of Yakutat Bay, at a long distance from the active vents of the Aleutian Islands or any recent volcanicity; the earthquakes of Japan are most numerous and severe in the non-volcanic parts of the islands; the great disasters of the Caribbean Sea have occurred in Jamaica and at Caracas, hundreds of miles from Mt. Pelé and St. Vincent's Soufrière, and have not been contemporaneous with any eruptions.

On the other hand, some of the most violent of historic volcanic eruptions have been unattended by severe earthquakes or have given rise to shocks of merely local significance. The Island of Martinique in the French West Indies lies within a markedly seismic zone, but the great eruptive activity of 1902–1903 was free from earthquake shocks. This fact is of particular interest, because the eruptions were of the most highly explosive character. Although, however, no vibrations were felt upon the island of Martinique and no subterranean noises were heard there, dull sounds like the booming of distant cannon were heard the morning of the great eruption of May 8, 1902, at Caracas, Venezuela, 450 miles distant, southwest, where people feared that a naval battle was in progress off their coast. Similar booming was reported from St. Kitts, 200 miles northwest of Martinique and from other regions. I myself was on the island of St. Vincent, 100 miles due south of Pelé when the great eruption of June 6, 1902, occurred, and I felt several dull thuds, as if some heavy object had fallen in a neighboring room. The noises seemed to come from beneath the ground, and they were due, in all probability, to subterranean explosions or to the rushing of lava into underground cavities, somewhat on the priniciple perhaps of the water hammer. On the island of St. Vincent some observers, indeed, had noted an increase of seismic shocks for a year or more before the volcano burst into violent eruption in May, 1902. The eruption itself, however, was free from earthquakes, except apparently for the quivering of the mountain due to the uprush of steam and ejecta through the conduit, just as happens in the chimney of a fire engine under full blast. The chattering vibrations thus set up in the volcano shook a narrow strip of recent beach formation from the west base of the mountain, where the declivity of the shore is considerable.

Vesuvius being the volcano that has been most continually and thoroughly under observation throughout its known history, we naturally look to its records for light upon the relation between volcanic eruptions and earthquakes. When this old center, which was not known to the ancients as a volcano, renewed its activity in the year 79, the first phase was a series of earth shocks which increased in frequency and severity until the afternoon of August 24, when the eruption actually began. The ground is said to have rocked to and fro like the sea, but we read of no great damage as resulting therefrom even in Pompeii and Herculaneum at the very base of the mountain. The outbreak of 1631 occurred after centuries of repose and was heralded by a half year of earthquakes and terrific noises in the interior of the mountain. This history has been repeated again and again in greater or less degree, particularly when the eruptions have been of the explosive kind. According to the report of A. Lacroix, violent earth movements shook the cone of Vesuvius during the great eruption of April, 1906, and were felt throughout much of the surrounding region. Whatever effects have been produced have been local in extent and comparatively light in degree.

The eruptions of Etna usually have been accompanied by the formation of great fissures in the upper part of the cone, and the opening of these fissures has been accompanied by severe vibrations of the surface of the mountain, as has been vividly portrayed by Silvestri in his account of the eruption of 1879, but the shocks seldom affect the mainland of Calabria across the narrow Strait of Messina. Stromboli, the "Lighthouse of the Mediterranean," often shakes its island, but the disturbances are rarely felt in nearby Sicily.

The most violent of all recorded volcanic explosions is that which took place in the Strait of Sunda, August 26–27, 1883, when the volcano of Krakatoa was blown to pieces. This outburst destroyed half the mountain and left soundings of 160 fathoms where part of the cone had formerly stood. It produced sea waves that affected tide gauges half way around the world; air waves that traveled three times around the globe before they ceased to be distinguishable; and it threw dust into the air to such a height that it remained suspended for months, but the earthquake shocks produced were strictly local in character and were scarcely felt at Batavia, 90 miles from the crater.

Another of the great explosions of modern times was that of July 15, 1888, when the Japanese volcano Bandai-san, extinct for a thousand years, burst into sudden eruption. In the immediate vicinity of the mountain a moderately severe earthquake shock lasting about twenty seconds was felt at half past seven in the morning. This was soon followed by additional shocks which culminated when the explosion occurred at the surface, but none was felt severely beyond a limited area.

Even the eruptions of the Hawaiian volcanoes, Kilauea and Mauna Loa, which are the types of the class of "quiet volcanoes," have sometimes been accompanied by severe local earthquakes. Many eruptions of Mauna Loa, indeed, have been recorded of which the first indication to the inhabitants of the town of Hilo only a few miles away has been the light seen at night reflected in the clouds from the streams of flowing lava. On March 27, 1868, however, there began a series of earthquakes on the southern flanks of the mountain which increased in frequency and intensity for a week and culminated in one of the most severe eruptions known in the history of the volcano, during which a great fissure opened, discharging vast quantities of lava that flowed to the sea.

In the words of Dr. Titus Coan,[7] who was on the island at the time:

[7] *Am. Jour. Sci.*, II., XLVI., 107, July, 1868.

Meanwhile the whole island trembled and shook. Day and night the throbbing and quaking were nearly continuous. No one attempted to count the sudden jars and prolonged throes, so rapid was their succession. And even during the intervals between the quakes, the ground and all objects upon it seemed to quiver like the surface of a boiling pot. The quaking was most fearful in Kau. . . . The shocks and quiverings cintinued with different degrees of intensity until Thursday, the second inst. [April] . . . when, at 4 P. M., a shock occurred which was absolutely terrific. All over Kau and Hilo the earth was rent in a thousand places, opening cracks and fissures from an inch to many feet in width, throwing over stone-walls, prostrating trees, breaking down banks and precipices, demolishing nearly all stone churches and dwellings, and filling the people with consternation. This shock lasted about three minutes.

Mr. F. S. Lyman[8] writes as follows of his experiences at Kau during this disturbance:

First the earth swayed to and fro from north to south, then from east to west, then round and round, up and down, and finally in every imaginable direction, for several minutes, everything crashing around and the trees thrashing as if torn by a hurricane, and there was a sound as of a mighty rushing wind. It was impossible to stand; we had to sit on the ground, bracing with hands and feet to keep from being rolled over. . . . The villages on the shore were swept away by the great wave that rushed upon the land immediately after the earthquake.

Some observers estimated that more than 2,000 shocks occurred during this period of disturbance. In spite of the violence of this earthquake on Mauna Loa, it was quite local in extent. No damage was done in the northern half of Hawaii even by the heavy shock of April 2. This shock was felt distinctly on the island of Maui, 110 miles distant, for 90 seconds, shaking furniture, pictures and walls and causing small sea waves. At Oahu, 210 miles from the centrum, the shocks were slight, and though they occurred in the middle of the afternoon, most of the inhabitants of Honolulu were not aware that an earthquake had occurred.

From the human standpoint, the most disastrous of the earthquakes assigned to volcanic causes is that which occurred at Casamicciola on the Island of Ischia, July 28, 1883. When it took place there was a large assemblage of people in the theater, which was of stone and collapsed under the shock, killing most of the audience. Only one house in the whole town was left standing and it is estimated that about 1,900 people lost their lives in the disaster. In

[8] *Am. Jour. Sci.*, II., XLVI., 110, July, 1868.

Naples, however, only twenty-two miles away, the shock was felt by but few people, and the seismographs in the observatory on Mt. Vesuvius did not record it at all, though the instruments at Rome and Florence showed the passage of some extremely light vibrations. The depth of the focus has been calculated at about a half mile and Casamicciola received the vertical shock. The latest eruption of Mte. Epomeo, Ischia's great volcano, occurred in 1302.

Many other instances of volcanic earthquakes might be cited, but perhaps none within historic times have been more severe than those which have been mentioned. All show extremely restricted areas of disturbance, a fact which indicates a comparatively slight depth for the origin of the shocks and a far smaller expenditure of total energy than is developed in connection with the great tectonic quakes. It must not be overlooked, however, that some earthquakes, the origin of which is doubtful, may rightly be assigned to a volcanic origin. Furthermore, the intrusion during past geologic time of countless dikes, sills and laccoliths of igneous rock, the occurrence of which is known from exposures all over the world, must have been accompanied by sudden dislocations, causing earthquakes. Such quakes would be of combined volcanic and tectonic origin. It cannot be asserted positively that they are not occurring at the present epoch.

This brings me now to the consideration of the third and most important class of volcanoes, viz., tectonic quakes, or those which are caused by dislocations in the earth's rock crust due to the action of mountain-building forces. Mountain regions of high geological antiquity, like the Appalachian protaxis and the Scandinavian Peninsula, have had time to adjust themselves to the crustal strains due to their elevation and hence are rarely the scene of great earthquake shocks. In the younger mountain systems, however, such as the Apennines, the Japanese archipelago, Central America and those of California, where young strata abut unconformably against old, the adjustment to strains is still going forward, the cumulative effect being followed by sudden and irregular release of pressure, producing the vibrations which we know as earthquakes. Some of these tectonic quakes have sensibly affected enormous areas. That of Lisbon, 1755, was felt from northern Africa on the south to

Scandinavia on the north and to the east coast of North America on the west, an area estimated by Baron von Humboldt at four times that of the whole of Europe. The Andean earthquake of 1868 shook severely a strip of country 2,000 miles long. The modern seismographs have given pronounced records of earthquakes whose origin was certainly not less than 8,000 miles distant—truly world-shaking events.

The depth of the origin of the shocks below the surface of the earth probably never exceeds thirty geographical miles and usually is not more than from five to fifteen miles. The geological structure of the region through which the earth waves are propagated affects the rate of advance of the same earthquake in different directions and produces many changes in the direction of movement and great differences in the destruction wrought upon buildings. Heavy earthquake shocks are transmitted through the earth at a greater velocity than light ones and the same shock shows different rates in different materials.

In the case of distant quakes three disturbances are recorded instrumentally. The first set of waves to arrive comes on a direct course through the earth's mass; the second set comes along the shortest route on the surface, while the third set arrives by the opposite and longest surface route. The last are comparatively feeble, and they may arrive three and one half hours behind the second set. The first set of waves, those coming through the earth, are propagated with the greatest velocity, which is practically uniform and is about ten kilometers (6¼ miles) per second. These direct waves have been shown by Marvin to be longitudinal in character, and this character combined with their velocity is supposed to cause them to give out the musical sounds which are the premonitory rumblings of an earthquake. The second set are the surface waves due to the "principal portion" of the earthquake, and the increased use of delicate instruments of measurement has led to the acceptance of 3.3 km. per second as their normal rate of propagation. The determination of these various velocities leads to the conclusion that the crust of the earth is practically uniform in constitution to a depth of at least thirty miles.

The duration of an earthquake and the number of shocks in it vary indefinitely. The Charleston, San Francisco, Kingston and many other quakes lasted only from thirty to forty seconds. Milne states that the average duration of 250 earthquakes of moderate intensity recorded by instruments in Tokyo between 1885 and 1891 was 118 seconds. The first shocks are almost always succeeded by after shocks which may continue for weeks, months or even years.

It has not been possible yet to determine the periodicity of shocks or to predict with any degree of accuracy the time of the occurrence of an earthquake. Some earthquake regions are subject to frequent shocks, while others experience them only at long intervals. The frequency of earthquakes, considering those of all amplitudes, is not generally realized. The globe, indeed, may be said hardly ever to be free from seismic disturbances of some kind somewhere, since the average of all recorded shocks, according to de Montessus de Ballore, is more than fifteen per day, and there are between fifty and sixty heavy shocks per year. The bare enumeration by this author of those occurring in 1903 alone fills a book of six hundred tabulated pages, and he has compiled the data and plotted the position of 159,781 earthquakes that have been recorded up to the end of 1903.

At the same time that important quakes are the result of tectonic movements in the earth's crust, they may themselves be the causes of more or less important changes in the surface of the earth. Sharp waves passing through mountain regions have been known to produce land slides, shatter rocks, displace larger or smaller segments of cliffs, open fissures in the soil or cause subsidence in alluvial regions. Springs, brooks, rivers and lakes have been formed, altered or obliterated as a result of earthquake action. Great earthquakes have usually produced important sea waves causing much destruction along the coast and, sometimes, permanent changes due to erosion and transportation of material.

Several scales for the purpose of indicating the severity of an earthquake shock have been proposed. The one most commonly employed is known as the Rossi-Forel scale, which distinguishes ten degrees of intensity according to the effects produced upon human observers and structures. Another widely used scale is that which has been devised by Professor G. Mercalli. This likewise consists of ten degrees of intensity and depends upon human observers and the effects upon buildings for the classification of a shock.

On account of the vagueness of these series, the influence of the personal equation of the observer in placing shocks in accordance with them and the over-importance attached by them to effects upon human property, other scales have been proposed, the best of which are based upon instrumental records. Difficulties in using the latter, however, arise through the small number of instruments actually at work, and the Rossi-Forel and Mercalli scales are still found very useful, particularly in the collection of data.

I shall close what I have to say regarding the subject of the afternoon by brief descriptions with illustrations of the earthquakes that occurred at Charleston, S. C., in 1886, at San Francisco in 1906, at Kingston, Jamaica, in 1907, and at Messina in 1908.

The Charleston Earthquake.

The most important earthquake occurring in the eastern part of North America during the historic period was that which devastated Charleston, South Carolina, in 1886. This was investigated under the auspices of the United States Geological Survey by Major Clarence E. Dutton and his assistants, their report being published in the Ninth Annual Report of the survey.

About eight o'clock in the morning of August 27, 1886, the villagers of Summerville, 22 miles northwest of Charleston, S. C., were startled by the noise and shock of what was at first thought to be a heavy blast or a boiler explosion. The sound seemed very near, but no cause for it was learned that day. Around five o'clock the next morning the noise and shock came again and more heavily, and the idea that an earthquake had occurred became general and was strengthened by light tremors that were felt that day and the next. The affair seemed then to be over, for nothing unusual was heard or felt on the thirtieth and during daylight of the thirty-first. The noises or shocks were felt by very few people in the city of Charleston, but they were the premonitions of the great earthquake that began at 9:15 P. M. of the thirty-first. In the words of Dr. G. E. Manigault, a resident of Charleston, as quoted by Dutton:[9]

Although the shocks at Summerville excited uneasiness in Charleston, no one was prepared for what followed. . . . As the hour of 9:50 was reached there was suddenly heard a rushing, roaring sound compared by some to a train of cars at no great distance, by others again to an escape of steam from a boiler. It was followed immediately by a thumping and beating of the earth underneath the houses, which rocked and swayed to and fro. Furniture was violently moved and dashed to the floor, pictures were swung from the walls and in some cases completely turned with their backs to the front, and every movable thing was thrown into extraordinary convulsions. The greatest intensity of the shock is considered to have been during the first half, and it was probably then, during the period of the greatest sway, that so many chimneys were broken off at the junction with the roof. The number was afterwards counted and found to be almost 14,000.

Apparently there were two maxima, the first of ten seconds duration, the second of six, with an interval of comparative quiet of 22 to 24 seconds. The whole period to be assigned to this destructive double shock is about 68 seconds.

Another observer states that four severe shocks occurred before midnight and that three others followed at about 2, 4 and 8:30 o'clock A. M.[10] Afterquakes occurred for months. Twenty-seven persons were killed outright and at least 56 more died from injuries received and exposure suffered. The money value of the property destroyed was estimated for Charleston alone at between $5,000,000 and $6,000,000. Not a building wholly escaped injury. Damage to buildings was greater on the low made ground than on the natural higher parts of the city.

The occurrence of visible surface waves was so definitely asserted by so many observers and with such detail of description that the fact of their formation cannot be discredited. The passing of such waves has often been included in the description of earthquakes, but their actual existence had been doubted, on account of the difficulty of explaining their origin. The amplitude of the surface waves in some parts of Charleston is estimated by Dutton at nearly or quite a foot and the average amplitude for the city at three or four inches.

[9] Ninth Annl. Rept. U. S. Geol. Survey, p. 231. Washington, 1889.

[10] *Op. cit.*, p. 217.

Besides throwing down walls and chimneys and moving houses bodily on their foundations, the earthquake caused wooden posts and brick piers to sink vertically into the earth; compressed railroad tracks into more or less complicated curves or stretched them apart; opened innumerable fissures in the ground, and formed hundreds or craterlets at many places out of which gushed water, sand and mud in copious streams.

The earthquake waves traversing Charleston were localized as coming from the northwest and from the west. The principal epicentrum was determined as being about sixteen miles northwest of the city and one mile from the little railway station at Woodstock, and a secondary epicentrum about fourteen miles due west of town. The focus of disturbance was a line or plane estimated as being twelve miles below the surface "with a probable error of less than two miles." The velocity of the wave motion throughout the eastern half of the United States was calculated as averaging 190 miles per minute. The intensity reached No. 2 of the Rossi-Forel scale as far away as New Orleans, Clinton, Mo., La Crosse, Wis., Saginaw, Mich., Burlington, Vt., and Boston—an extreme radius of about 1,000 miles. The Charleston earthquake is classed as a tectonic quake, though no evidence of faulting was apparent on the surface.

(Lantern slides were shown depicting the destruction of buildings in Charleston and vicinity and the formation of fissures and craterlets.)

The San Francisco Earthquake.

California has always been known as a seismic region. Professor E. S. Holden has catalogued 514 shocks, 254 of which affected the region of San Francisco alone, within the period between 1850 and 1886. During the nineteenth century there were ten severe quakes; that of 1868, known as the Mare Island quake, having such a disastrous effect upon the city of San Francisco that serious doubts were entertained of the advisability of rebuilding on the same site, but these fears were soon forgotten and the city rapidly rose again. It was rebuilt, however, without much reference to the lessons that might have been learned from the experience.

In the Sierra Nevada, forming the eastern half of the state, earthquakes are likewise frequent. In 1872 occurred the great Owens Valley quake, which was one of the most severe on record and was the result of movements producing a series of faults along a line more than 100 miles long with a throw of from ten to twenty feet. This mountain system is formed of Precambrian granites, gneisses and schists, upon which have been laid down upon the west an unconformable series of late Paleozoic and Mesozoic strata. The coast ranges, in which the earthquakes occur with far greater frequency, are composed of a granitic core against which rest extensive Mesozoic and Cenozoic strata upon which are thick marine Pleistocene and recent beds. The latter are full of the fossil shells of still living species of mollusks and show that elevation is still going forward in California.

The San Francisco Peninsula is traversed by at least five known lines or zones along which movement, or faulting, has occurred again and again. The principal of these zones is the San Andreas, which takes its name from an important lake through which it runs. It is likewise known as the Stevens Creek fault, as the Portolá-Tomales fault or more simply as "the rift." This zone continues northwest in a slightly curved line to Point Arena and southeast to the mountains west of Hollister. This is the continuous extent of the fault, some 190 miles, but it probably extends under the ocean beyond Cape Mendocino to the north and into the mountains southeast of the line recently disastrously affected.[11] According to H. W. Fairbanks[12] the recognized rift extends from Shelter Cove, Humboldt County, as far southeastward as the Colorado desert and is 700 miles long. Dr. Fairbanks states further that the great Tejon earthquake of 1857 was caused by movement in the same fault zone.

The recurrence of horizontal and vertical movement along the northern 200 miles of this fault line caused the earthquake which at

[11] "The California Earthquake of 1906," by David Starr Jordan and others. G. K. Gilbert, map, p. 317. San Francisco, 1907.

[12] "The California Earthquake of 1906," pp. 321–337. See also "Report of the California State Earthquake Investigation Commission," by A. C. Lawson, chairman, p. 48. Washington, 1908.

5:12 o'clock A. M., western time, April 18, 1906, wrought ruin or serious damage over a belt 50 miles wide and 300 miles long. The approximate position of the epifocal point of the disturbance is given by F. Omori as being in latitude 38° 15′ N. and longitude 123° W., near Tomales Bay.[13] The horizontal shearing movement varied from nine to twenty feet toward the N.N.W. or the S.S.E.; the vertical movement did not exceed two feet at any locality and usually was absent, upthrow where present being on the west side of the rift. Among the effects along the line of the fault were rifting and bulging of the soil, offsetting of fences, roads and walks, splitting and overturning of trees, landslides in the mountains, wrecking of railway tunnels, spreading and telescoping of lines of waterpipe. This is the most disastrous earthquake that has visited the United States, though the chief destruction wrought was due to the fire that followed in the train of the quake rather than to the shock itself. About four hundred people are known to have lost their lives in the catastrophe, and at least $350,000,000 worth of buildings and other property were ruined by the shock or consumed by the flames. An exact statement of the pecuniary loss caused by the shock cannot be made, but the insurance companies finally agreed upon a settlement to the effect that one-fourth of the damage was due to the earthquake and three-fourths to the fire, and this estimate may be accepted as the best that can be made. More than four square miles of the city of 400,000 inhabitants was devastated.

The main part of San Francisco lies about eight miles northeast of the fault line, and the propagation of the waves through the city was in a direction N. 76° E., nearly normal to the fault line. In general the advance of the wave motion on each side of the rift was away from it. Omori concludes that both sides of the fault line were displaced toward the N.N.W., the west side more than the east, the amount of apparent slip being merely differential. In San Francisco the chief damage was wrought upon structures built upon alluvial or made ground. High steel-frame structures which were not stiffly braced acted like inverted pendulums, causing ruin to their walls. This was illustrated in the case of the City Hall in San Francisco and the library buildings at Stanford University

[13] "The California Earthquake of 1906," p. 289.

and the City Hall at Santa Rosa. The main source of the earthquake is thought to have been situated at a considerable depth below the surface (Omori).

(Lantern slides were shown to illustrate the destruction of buildings in San Francisco, Santa Rosa and Leland Stanford Jr. University, and the geologic and topographic changes wrought in the surface of the ground along the line of fracture.)

The Kingston Earthquake.

The Blue Mountains, rising 7,400 feet above the level of a sea 18,000 feet deep, form the back-bone of the island of Jamaica. They trend northwest-southeast and, according to Robert T. Hill,[14] from the earliest axis of folding now apparent. Upon this have been super-imposed later east-west flexures corresponding with the crustal movements that early in the Mesozoic era determined the chief characteristics of the Greater Antilles. Charles W. Brown,[15] reports observing "transverse faults in the Blue Mountain region which undoubtedly indicate lines along which fractures may occur." Professor Hill assumes an east-west axis of folding with an anticline producing the trend of the Greater Antilles and leaving a parallel syncline coinciding with the Bartlett Deep just north of Jamaica.

Such strong relief coupled with folding indicates a high state of tension in the earth's crust. Resistance to stress is diminished on steep slopes, especially when the application of pressure to the ends of an axis is not made in the same plane, giving rise to torsional strains. Fracturing results, tending to follow old fault planes, and these fault planes were originally determined by zones of weakness in the rocks. Fracturing, as we have seen, produces earthquakes. Montessus de Ballore acquiesces in the folding postulated by Hill and embraces the Greater Antilles, including Jamaica, within the great Alpine geosynclinal. The region experiences frequent shocks and one of the most dreadful disasters of modern times occurred within it in the year 1692, when, as a result of an earthquake, the greater part of Port Royal, the capital of Jamaica, sank into the

[14] *Bull. Mus. Comp. Zoöl.*, Vol. XXXIV., p. 164.

[15] *Popular Science Monthly*, Vol. LXX., p. 385, May, 1907.

sea. The city was built upon a narrow sand spit formed of the detritus brought down by rivers from the mountains of the interior or cast up by the sea. It is estimated that 2,000 people lost their lives in this disaster, when a tract of land about a thousand acres in extent sank so as to lie thirty or forty feet under water.

After the destruction of Port Royal the city of Kingston was established on the gradually rising Liguanea plain across the harbor from the old capital, and it flourished for 215 years, becoming a compact city of 60,000 inhabitants. Its business portion extended along the water front and was only twelve blocks long and two wide. The city was built, however, upon unconsolidated gravels and sands —alluvial and coast deposits that gave a foundation but little more secure than the sand spit gave to old Port Royal. Hence when the earthquake of January 14, 1907, occurred, 85 per cent. of the buildings in the city was injured or destroyed, and fire completed the ruin over ten or fifteen blocks of the business and warehouse section.

The shock probably began at 3:33 P. M., though an exact statement cannot be made through lack of accurate standard time in the island. This defect as to time has made it impracticable to plot any coseismal lines. The first series of vibrations, the great shock, lasted 35 seconds, more or less, but the duration varied with the position of the observer. The longest period was reported from the north shore and as being 90 seconds. After the preliminary tremors, which were heard before they were felt, the shock was double, the first maximum being reached in about ten seconds, followed by a second and less acute climax before the vibrations ceased. The interval between the preliminary tremors and the main shock was almost insensible. After shocks occurred for several months. Through the city of Kingston and its immediate vicinity the earthwave shown by the first climax passed from west to east, but three miles north of town the direction of motion was distinctly from the south, while in the Hope River valley five miles east of the city, the advance was from the northwest. The earthwave recorded by the second maximum of shock was more undulatory in character than the first and seems to have originated more to the south of the city. This direction of motion combined with the first produced a twisting counter-clock-wise movement of slender upright structures like statues, columns and chimneys and had a noticeable effect on buildings.

According to Professor Brown:

> The dip of the angling cracks at Kingston points to a locus of disturbance much to the west of that city, while the lines of isoseismals indicate the intensity area to be in the eastern half of Kingston. . . . The only conclusion then is that the eastern end of the Liguanea plain was the nearest area to the real epicenter that by nature of material would give the greatest amplitude to the destructive epifocal waves. Further, the angle of emergence at Kingston coördinated with the proximity of a probable epicenter together with the limited area of disturbance indicates a shallow origin of about three miles.

As is demanded by theory and observed in fact the vibrations increase in violence on passing from an elastic to an inelastic medium—the destruction wrought in Messina, San Francisco and other places has been worse in the sections built upon alluvial or other loose soil than in those built upon rock, and Kingston was entirely upon such loose material. The experiences of these and other regions show that the destructiveness of an earthquake is not necessarily greatest in the epifocal area. If the locus of disturbance is in or under an elastic rock-mass and the shock is propagated into a region of inelastic loose material, the destruction in the latter may exceed that in the real epicenter. The fault which was the locus of the San Francisco quake is some miles from the city.

The shock of the Kingston earthquake was not sensible on the island of Haiti to the east or on Grand Cayman to the west, but Santiago de Cuba, 120 miles to the north, felt it slightly. This indicates an ellipse as being the generalized form of curve for the isoseismals, with the longer axis extending approximately north and south. At Annotta and Buff Bays on the north shore of Jamaica, opposite Kingston, the destruction wrought was almost as severe as at the capital city. The inference is that renewed faulting along north-south fault lines caused the earthquake.

The building construction of Kingston was as bad as the foundation upon which the city rested. Brick structures predominated, but for the most part it was evident that the brick had been laid dry in poor mortar. Such buildings collapsed under the shock. Those that were properly put together withstood the quake better. Wooden houses with good braces and well fastened together were not thrown down. Massive walls showed cracks from half an inch to two inches wide. The double amplitude of the wave motion of the earth is estimated at not more than one inch. Such an amplitude is small when compared with the four-inch amplitude calculated by Omori[16] for the earthwave of the San Francisco (1906) quake, the 6 to 12-inch amplitude estimated by F. A. Perret[17] for the earthwave at Messina in last December's quake, or the one foot maximum amplitude given by C. E. Dutton[18] for the Charleston earthquake wave. These largest estimates were derived from effects in soft ground and are probably excessive.

From a geological standpoint the movements causing the Kingston earthquake were less important than the changes in the earth's surface that were produced by it. Surface evidence of the former has not yet been discovered, but the latter are quite apparent. Beginning in the city water front, a belt of fissuring and subsidence skirted the eastern half of the harbor and returned along the inner (northern) base of the Palisadoes. Opposite the city the zone of disturbance forked, one branch maintaining the original direction and passing through Port Royal, while the other curved northwestward touching Ft. Augusta and dying out in the River Cobre valley, eight to ten miles northwest of town.

From soundings taken for Professor Brown, it was learned that "in several places along the edge of the harbor the bottom had sunk from old soundings of a fathom and a half to over six fathoms, and that on the harbor side of the base of the Palisadoes a series of step faults reached a maximum depression at the shore to the north of four fathoms." Port Royal sank from 8 to 25 feet. The zone of disturbance was from 100 to 300 yards wide, containing where exposed many fissures and craterlets out of which water, sand and mud gushed to heights of three or four feet. The fissuring was caused by the compression and expansion of the earth due to the passage of the earthquake wave, but the cause of the subsidence is not clear, for the harbor as a whole did not sink—only an encircling belt. Perhaps solution of the soft limestone where

[16] "The California Earthquake of 1906," p. 307, 1907.

[17] *Am. Jour. Sci.,* IV., XXVII., 327, April, 1909.

[18] Ninth Annual Rept. U. S. G. S., p. 269. Washington, 1889.

the ground waters enter the harbor left caverns into which the overlying material was shaken by the quake (Brown). No sea wave of importance accompanied or followed the shock.

(A series of lantern slides was used to show the destruction caused in the city, the sinking of Port Royal point and the faulting, fissuring and formation of craterlets along the Palisadoes.)

The Messina-Reggio Earthquake.

Time after time during the historic period Italy has suffered from the effects of serious earthquakes, but never before so severely as from that which occurred in Calabria and Sicily on December 28, 1908, when 200,000 human beings are supposed to have lost their lives. The cities of Messina in Sicily and Reggio in Calabria were completely wrecked, and many other villages and towns were laid in ruins or damaged throughout an irregularly elliptical district 85 miles long by 50 miles wide, extending from Pizzo, Calabria, on the northeast to Riposto, Sicily, at the sea base of Mt. Etna, on the southwest. The epifocal area was the Strait of Messina, with the epicentrum at or near the northern end of the Strait. More precisely, the longer axis of the ellipse of greatest destruction (from Ali to Palmi, about 35 miles), as shown by isoseismals, lies in the strait and runs N.N.E.–S.S.W.

Calabria and northeastern Sicily form a district of extreme seismicity that has been visited by several disastrous earthquakes, among which those of 1783, 1785 and 1905 stand out with prominence on account of their destructiveness to human life and property. Volcanic quakes have been associated with eruptions of Mt. Etna, but they have been strictly local in effect, and their influence has not been seriously felt across the Strait. All the severe shocks have originated in Calabria or under the Strait of Messina are of tectonic character, the geological structure being particularly favorable to the production of such quakes. Forming the backbone of Calabria and extending beyond Messina in Sicily there is an elongated area of Archean gneisses and mica schists. Along this axis there occur nearly horizontal beds of Miocene age up to an altitude of 3,300 feet above the sea, while along the Strait of

Messina there runs a fault with thousands of feet of throw, the uplift being upon the Calabrian side of the Strait. Movement appears to be still going on along this and other fault zones, resulting in repeated earthquakes. Furthermore, the slopes into the submarine depths on both sides of the "toe" of Italy are very steep and therefore unstable.

Toward the end of 1908 the seismic activity of the region was evidently on the increase, and noteworthy shocks were felt November 5 and December 10, while F. A. Perret[19] reports that at 5:20 A. M., December 27, just twenty-four hours before the occurrence of the great shock, the seismograph at the Messina observatory registered an important earth movement. The observatory was wrecked by the great earthquake, but the instruments had been installed in its cellar and Dr. E. Oddone[20] of the seismographic service found them intact and the records intelligible, when he reached the place January 1. These records showed that the quake began at 5:21:15 o'clock A. M., December 28, with a gentle movement the force of which increased during ten seconds and then diminished during ten seconds. After two minutes of calm came the great shock, lasting 30 to 35 seconds, which was recorded by seismographs all over the world. This was followed by comparatively light shocks at 5:45, 5:53 and 9:05 o'clock A. M. of the same day, and by noteworthy quakes at 2:51 and 7:30 o'clock P. M. of the following day. For several days and even weeks minor shocks continued to occur. Some of these "after-shocks" were strong enough to add to the damage caused by the principal quake. According to Mr. Perret[21] the intensity within the megaseismic area was between the ninth and tenth degree of the Mercalli scale decreasing rapidly with increasing distance from the epicentrum, and the centrum was not deeply located, being possibly fifteen kilometers ($9\frac{3}{8}$ miles) beneath the surface.

Messina was a beautiful city stretching for miles along the shore of a magnificent harbor. Lying in an advantageous position on the short cut from the Eastern Mediterranean to the Tyrrhene

[19] *Am. Jour. Sci.*, IV., XXVII., p. 321, April, 1909.

[20] *La Nature*, XXXVII., 103, January 16, 1909.

[21] *Loc. cit.*, p. 321.

Sea, the city has enjoyed prosperity for centuries, in spite of frequent visitation from earthquakes. The city was almost completely destroyed by a shock in February, 1783, but the people seem to have learned nothing from their experience with an unstable land. The Messina of yesterday—the city does not exist to-day—was constructed of stone and rubble and old cement. The buildings lined narrow streets and were three, four and even five stories high with massive walls. Hence when the shock came and raised and then dropped the ground for half a minute, the houses, stores, hotels, churches and government buildings were shaken into unrecognizable heaps of débris, filling the sites of the structures and obliterating the streets. The sea-wall in front of the city was partly destroyed, and the promenade along the harbor sank in places below the water.

Reggio di Calabria likewise has suffered frequently from earthquakes, but until within the past few years the inhabitants had not profited by experience to put up earthquake-proof buildings, and all the old houses in the city were demolished by this latest quake. New houses not more than ten meters (33 feet) high are said to have resisted the shocks perfectly. Throughout the Calabrian earthquake district the buildings erected since the disaster of 1905, according to the specifications of the Milan Committee, are reported to be intact in spite of the severe shaking thus received, but all these are low structures.

Photographs show that there was some fissuring of the ground at Messina, and it is reported that "vast chasms" were opened at both Messina and Reggio, but the latter statement is probably incorrect. Professor G. B. Rizzo is quoted as stating[22] that the sea bottom rose in some places, for he saw several boats out of water at the places where they had been anchored some distance from the original shore. The extensive breaking of telegraphic cables indicates submarine disturbance, but the fact of any considerable change in the configuration of the sea bottom remains to be proven and can only be established by careful soundings. No changes in the coast line have occurred, as far as can be detected without an

[22] *Nature,* Vol. LXXIX., p. 289, January 7, 1909.

instrumental survey. It is stated positively that the ground sank in several places in Messina, Reggio and elsewhere, particularly along the harbor front in Messina and along the sea front and in the center of Reggio; but all the low-lying parts of the two cities were built upon unconsolidated alluvial and shore material, permitting, as in the earthquakes of San Francisco and Kingston, severe and destructive oscillations and displacements.

As is usual with shocks occurring along or near the seacoast, the earthquake was accompanied by a "tidal wave," the sea retreating for a considerable distance and then returning into the strait with growing force. The wave was not at all violent in the deep water of the strait and was of importance only as it came into the shallower water near shore, where it was eight or ten feet high. Its crest swept across the marina, or esplanade, bordering the harbor at Messina two or three minutes after the great earthquake shock occurred, and some comparatively slight damage is assigned to the water. The wave was somewhat higher at Reggio than at Messina and attained its maximum on the coast south of Taormina (Perret). In Reggio the buildings on the low land along the coast were flooded. The wave injured a few boats at Syracuse near the southeastern corner of Sicily; but it was scarcely perceptible at the Island of Malta, about 165 miles south by east of Messina, where it arrived at 7:15 o'clock A. M. The sea gauge at Ischia, about 190 miles north-northwest of Messina registered maximum oscillations of 22 centimeters (8.6 inches) at 2:30 o'clock P. M. and at 8 o'clock P. M. If the former was due to the quake that destroyed Messina and Reggio at 5:25 o'clock that morning the rate of advance northward was much less than it was southward.

(A series of slides was shown illustrating the effects of the earthquake in Messina, Reggio di Calabria and Scylla.)